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PAR AURORAL STUDY

VOLUME II. A TECHNIQUE FOR STANDARDIZING THE PROCESSING OF AURORAL RADAR BACKSCATTER DATA

M AND S COMPUTING, INCORPORATED
HUNTSVILLE, ALABAMA

19 MAY 1976

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PAR AURORAL STUDY

VOLUME II

A TECHNIQUE FOR STANDARDIZING THE PROCESSING OF AURORAL RADAR BACKSCATTER DATA

M&S COMPUTING, INC.

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18. SUPPLEMENTARY NOTES

This is one of six volumes of reports that present the aurora borealis data collected by a multimegawatt phased array radar. The radar has excellent sensitivity and range resolution affording very precise aurora detail.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Aurora borealis, phased array radar, radar/aurora effects, backscattering characteristics, radar reflectivity, Geomagnetic Field effects.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The topic of radar reflectivity of aurora effects is discussed. The report describes a method for representing the volume backscattering characteristics of auroral irregularities. The objective was to develop a universal relationship for calculating the aurora reflectivity. The expression would then normalize all radar-dependent parameters, including geographic location. In attempting to derive a classical solution to the problem, some ambiguous terms remain. However, the technique should prove useful for making certain limited comparisons of data from different radars.

PREFACE

The age of space technology has been characterized by great strides in the science of ionospheric geophysics. The level of knowledge in this field has been greatly expanded in recent years largely because of the data collected by a number of space probes. The results of the many studies of phenomena exhibited in the ionosphere and magnetosphere suggest these interactions may influence environmental factors on the earth's surface. One of the most dramatic ionospheric phenomena is the aurora. Throughout history it has awed millions, influenced the decisions of leaders, and been contemplated by thinkers. Today, it is better understood, but its powerful effects on our modern communications equipment are readily evident. Studies of the effects of aurora on communications not only help to develop ways to cope with these effects, but simultaneously broaden our level of knowledge of the phenomena itself.

An important field of auroral research involves the reflection of radar signals from the aurora. There have been a number of such studies each yielding valuable information to the scientific community; still there is much to learn about this phenomena. Radars with more powerful transmitters and higher resolution, controlled by high performance digital computers, are now available to allow present researchers to build on the studies of those hampered by the lack of such equipment. Likewise, the nature of data collected by these advanced radar systems makes practical new techniques for the processing of this auroral backscatter data.

With the prospects of continued studies of radar/auroral effects, it is apparent that a need exists for the standardization of certain types of computed parameters. This standardization could greatly benefit the investigators by simplifying the task of comparing the results of measurements made by different radars.

The techniques discussed in this paper were developed in conjunction with the auroral studies performed by M&S Computing, Inc., under Contract No. DASG60-74-C-0026 for the Army Ballistic Missile Defense Command in Huntsville, Alabama. PAR Auroral Study, Volume II, dated May 19, 1976, constitutes M&S Computing's Report No. 76-0016.

Prepared by:

M. J. Mitchell

Approved by:

W E Salter

Dr. W. E. Salter

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1. INTRODUCTION

This report describes a method for representing the volume backscattering characteristics of auroral irregularities. Ideally, the goal is to determine a universal relationship for calculating this property. This relationship should normalize all radar-dependent parameters including geographic location. If it were possible to develop such a technique, it would greatly enhance the comparison of measurements from various radars. Unfortunately, the development of a universal term is replete with pitfalls, as undefined variables abound.

Section 2 of this report provides a derivation of the classical solution to the problem. This technique defines a method for calculating a parameter which may be used to represent the auroral volume reflection properties. Some ambiguous terms are, however, still present in the resulting solution. These parameters will have been minimized, identified, and grouped. This technique will not have solved the entire problem, but the resulting measurements can be useful for making certain limited comparisons of data from different radars.

Section 3 includes a general discussion of how the unnormalized backscatter data may be used in auroral analysis, emphasizing the necessary considerations required for making comparisons of data from different radars. A technique will be proposed which could be used to resolve certain ambiguities in the initial calculations. Even though there exist numerous quantities of data which suggest the feasibility of such an endeavor, there is some uncertainty in the approach. This problem is compounded by the difficulty in testing the results. Comparative testing requires the processing of data from simultaneous measurements by two or more radars. It is hoped that this discussion might stimulate others to join in a cooperative plan for developing, testing, and perfecting a standardized technique for representing the volume reflecting properties of the aurora.

The final section describes the auroral studies being performed at M&S Computing, Inc. The primary subject of this discussion involves techniques which may be used in the selection of data in order to improve the quality of the analysis results.

2. THE BASIC AURORAL RADAR REFLECTIVITY*

Auroral radar backscattering is generally assumed to result from the partial reflections of the impinging electromagnetic wave at the boundary of a sharp change in free electric charge density. There is no generally accepted theory explaining precisely the characteristics nor the mechanism which forms these irregularities, but considerable data is available from previous auroral backscatter measurements. These data indicate the reflecting irregularities occuring in the ionosphere E-region (about 100 km) and are aligned with the earth's magnetic field. The fact that precipitating charged particles are constrained to spiral in along the earth's magnetic field lines suggests this observation is probably correct. The numerous monostatic radar measurements of aurora show that the energy in the signal backscattered to the radar is related to the angle between the radar beam and the earth's magnetic field lines at the reflecting point. This "aspect sensitivity" may exist because the electromagnetic wave will be reflected from the field-aligned scatterer as dictated by classical optics such that the angle of incidence equals the angle of reflection. The reflected energy will, thus, be maximized when this angle is near 0^{o}, i.e., when the radar is pointed perpendicular to the magnetic field lines. A more detailed theory on the aspect dependence of auroral backscatter measurements has been presented by Booker.[1]

Many auroral scatterers occupy each range resolution cell of all radars which have been used to study aurora. It is apparent that resolution will have to improve manyfold before single scatters may be observed.

Much of the auroral backscatter data available from past measurements has been presented in a fashion whereby the measured results are given in terms of received signal strength. In order to compare these measurements with those from another radar, one is required to examine the numerous radar parameters which contribute to the resultant measured backscattered power. By calculating the auroral reflectivity, most of these parameters can be normalized or factored out, thus reducing the bulk of the ambiguous parameters confronting the researcher. The ambiguities remaining in the reflectivity term, though difficult to isolate, allow

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*Examination of available literature has yielded numerous terms used to represent volume-reflection properties. The term, "reflectivity", common to radar theory, appears to be the most suitable name for the properties described herein.

[1] Booker, H. G., J. Atm. Terr. Phys., 1956, pp. 8, 204.

the researcher, through careful choice of data to make some comparative observations.

2.1 Reflectivity Derivation

The purpose of this section is to derive the equations which will be used to represent the backscattering properties of the aurora. Many of the parameters which are dependent upon the properties of the observing radar will be factored out. One important process which will be described is that of representing the volume reflecting properties of the aurora. Whatever properties of aurora are responsible for the backscattering, they cannot be viewed as discrete scattering elements. Furthermore, with the beamwidths and range resolution presently available, many scattering irregularities are simultaneously illuminated such that the received echo is really a superposition of many smaller signals. It is clear that auroral backscatter will have to be treated as a volume scattering phenomena.

To initiate the derivation it is convenient to imagine a region containing reflecting irregularities being observed by the radar. For analysis purposes, the radar cross section of each scatterer will be expressed in terms of its equivalent radar cross section per unit of volume. In other words, the scatterer will be treated as if it had the same radar cross section σ_{Tm} m^2/m^3, as an object which reradiated, uniformly in all directions, all power incident upon it.

The power density P_i incident upon a scatterer at a range R from the illuminator is given by

$$P_i = \frac{P_T G_T L_T L_{P1}}{4\pi R^2} \quad W/m^2 \qquad (2.1)$$

where P_T is the peak power measured at the transmitter, G_T is the gain of the transmit antenna compared to an isotropic radiator, and L_T represents system losses in transmitted power. L_{P1} represents the one-way loss along the propagation path.

A scatterer in the far field of the radar will reflect a portion of the incident power back to the receiver. At the receiver the measured power from a scatterer of unit volume is given by

$$P_r = \frac{P_T G_T A_e \sigma_{Tm} G_s(\alpha) L_R L_{P2} L_T L_P}{\left[4\pi R^2\right]^2} \quad W \qquad (2.2)$$

where A_e is the effective aperture of the receiving antenna in the direction of the target and L_R represents the net change in received signal strength from the antenna to the signal detector. L_{P2} represents the one-way signal loss over the return propagation path. Normally L_{P1} and L_{P2} are equal and so the total two way loss factor will be represented by L_{P1}^2 where σ_{Tm} is the instantaneous radar cross section per unit volume which would be measured if the angle α between the propagation path and the earth's magnetic field were 90^o at the reflecting point. The $G_s(\alpha)$ term is a yet undefined variable which describes the scattering aspect dependence. The aspect relation $G_s(\alpha)$ will be combined with the effective target cross section parameter σ_{Tm} such that the target parameter contains the aspect dependence given by

$$\sigma_T(\alpha) = \sigma_{Tm} G_s(\alpha)$$

In the direction broadside to the antenna the effective aperture of the antenna can be expressed in terms of its gain and operating frequency as given by [2]

$$A'_e = \frac{G_R \lambda^2}{4\pi} \quad m^2 \tag{2.3}$$

where G_R is the broadside gain of the receiving antenna. In the general case, *for a fixed-face phased array*, the effective aperture projected in the direction of the target is given by

$$A_e = A'_e \operatorname{Cos}^3 \rho \quad m^2$$

where ρ is the angle between antenna broadside and the target direction. Phased array radars also require a correction to account for degradation of the array element antenna pattern as it is steered off broadside. The power pattern of phased array dipole radiating elements is generally approximated by

$$G(\rho) = G(0^o) \operatorname{Cos}^3 \rho$$

Element pattern degradation affects both the transmitted power incident on the target and the power received. The $\operatorname{Cos}^3 \rho$ correction is thus applied to both the gain of the transmit array and the receiving array.

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[2] Nathanson, F. E., Radar Design Principle, McGraw-Hill, 1969, p. 1, 7.

The resultant received power from a scatterer of unit volume is obtained from equations (2. 1), (2. 2), and (2. 3).

$$P_r = \left[\frac{P_T G_T G_R \cdot \lambda^2 \cdot L_R \cdot L_T}{(4\pi)^3}\right]\left[\frac{\cos^3\rho \, \sigma_T(\alpha) L_P}{R^4}\right] \quad W \qquad (2.4)$$

When multiple scatterers are present, it can be shown that the reflected power measured at any instant at the receiving antenna is determined by the vector sum of the incident E field components reflected by all scatterers in a volume determined by the radar beamwidth and effective pulse width. Because the scatterers are constantly reshuffling, their individual phase and amplitude contributions rapidly change. The measured resultant of these signals also changes. By averaging many separate measurements from the same region, the mean intensity can be determined.

If measurements are taken in an elemental volume (dv) of space completely filled with auroral scatterers, the differential of power received by the radar from this volume is given by

$$d\,Pr \left[\frac{P_T G_T G_R \lambda^2 L_T L_R}{(4\pi)^3}\right]\left[\frac{\cos^3\rho L_P \sum \sigma_T(\alpha)}{R^4}\right] \quad W \qquad (2.5)$$

In order to determine the total received power from all scatterers in the beam, it is necessary to integrate over the total region being illuminated. This operation can be approximated if the antenna gain is assumed constant over an effective illuminated volume (V_{eff}), yielding

$$P_r = (\text{radar terms}) \cdot (\text{Target terms}) \cdot V_{eff} \qquad W \qquad (2.6)$$

In order to determine this effective volume, it is necessary to define the range resolution cell. The length in range of this cell is determined by the minimal radial separation of two equally reflecting in-line targets which can be individually resolved by the radar. The instantaneous power from the center of this cell represents the contributions of all scatterers in the illuminated cell. In the case of pulsed CW radars, the length of this cell is equal to $\frac{c\tau}{2}$ where c is the speed of light and τ is the pulse width. As the pulse passes through the reflecting volume, reflected energy from the first half of the pulse will arrive earlier and be separated from the energy reflected from the last half. In a chirped radar the long pulse of width $c\tau$ will simultaneously illuminate a region of large radial extent but because of the frequency modulation, the scatterers at different ranges in the pulse are being illuminated by different frequencies. This means that when pulse

compression occurs in the signal processor the signal energy regains its proper time structure. The resolution cell is now determined by the compressed pulse width τ'. The resulting cell width is then given by

$$R = \frac{c\tau'}{2} \qquad \text{meters}$$

To further define the volume associated with the resolution cell, some facts about the nature of aurora must be considered. Some researchers have suggested that the reflecting region often takes the form of a relatively thin band or arc approximately 5-20 km thick, centered at about 110 km in altitude. If this thin arc were intersected by the beam at a relatively low elevation as depicted in Figure 2-1, the thickness of the auroral arc might be too small to completely fill the beam. For this case the "effective" cell volume illuminated by the radar may be approximated by

$$V_{eff} = R\Theta\Delta H\Delta R \qquad m^3$$

or

$$V_{eff} = R\Theta\Delta H \frac{c\tau'}{2} \qquad m^3$$

In many cases the arc fills the beam; for these cases the approximation becomes

$$V_{eff} = \pi\left(\frac{R\Theta}{2}\right)\left(\frac{R\phi}{2}\right)\left(\frac{c\tau'}{2}\right) \qquad m^3$$

which upon combining terms yields

$$V_{eff} = \frac{\pi}{8} R^2\Theta\phi c\tau' \qquad m^3 \qquad (2.7)$$

where Θ and ϕ are small angles measured in radians.

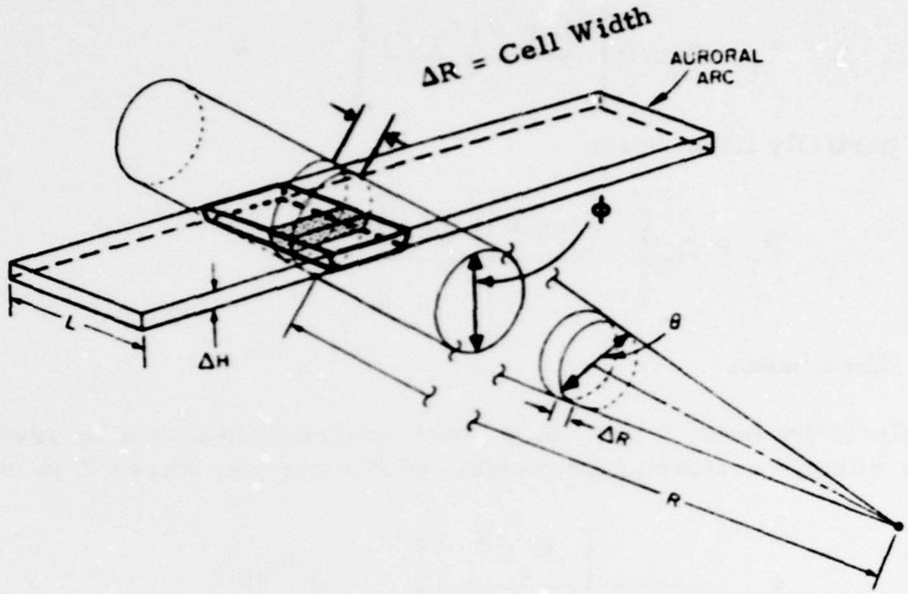
For the case of the partially filled beam the previous equations are combined and if $G_T = G_R = G$ one obtains:

$$\bar{P}_r = \frac{P_T G^2 \lambda^2 \Theta\Delta H c\tau' \operatorname{Cos}^3\rho\, L_T L_R L_P \sum \sigma_T(\alpha)}{128\pi^3 R^3} \qquad W \qquad (2.8)$$

For the beam filled with scatterers:

$$\bar{P}_r = \frac{P_T G^2 \lambda^2 \Theta\phi c\tau' \operatorname{Cos}^3\rho\, L_T L_R L_P \sum \sigma_T(\alpha)}{512\pi^2 R^2} \qquad W \qquad (2.9)$$

SCHEMATIC REPRESENTATION OF FILLED BEAM
AND AURORA INTERSECTION



Note: The majority of all data analyzed at M&S Computing has shown auroral arc heights of about 40 to 60 km.

Figure 2-1

The terms in the summation will henceforth be called the radar "Reflectivity" or Z.

The constants in (2.8) and (2.9) will be combined in Q_p and Q_F yielding the following equations. We have

$$\bar{P}_r = Q_p \Delta H \left[\frac{\left(\mathrm{Cos}^3 \rho\right) L_P Z_P}{R^2} \right] \quad W \tag{2.10}$$

for the partially filled beam

$$\bar{P}_r = Q_F \left[\frac{\left(\mathrm{Cos}^3 \rho\right) L_P Z_F}{R^3} \right] \quad W \tag{2.11}$$

for the filled beam.

The reflectivity term Z has, thus, been derived which can be used to represent the volume scattering properties of the aurora, where Z is now given by

$$Z_P = \frac{1}{Q_P \Delta H} \left[\frac{\bar{P}_r R^3}{L_P \left(\mathrm{Cos}^3 \rho\right)} \right] \quad m^2/m^3 \tag{2.12}$$

$$Z_F = \frac{1}{Q_F} \left[\frac{\bar{P}_r R^2}{L_P \ \mathrm{Cos}^3 \rho} \right] \quad m^2/m^3 \tag{2.13}$$

3. APPLYING REFLECTIVITY TO AURORAL ANALYSIS

The reflectivity terms just developed are definitely not a panacea for all researchers frustrated by the difficulty in making comparative measurements with other radars. Although the majority of the radar-specific terms have been factored out, the Z-term still harbors a number of unresolvable, ambiguous parameters. The most important of these is aspect sensitivity. Each radar, in general, is constrained to observe the aurora from a different location. Each location is oriented in a different way with respect to the earth's magnetic field and, thus, when each is observing the same region of space, the aurora may appear much different.

Another problem is that the auroral backscatter mechanism is frequency dependent; Z is a function of frequency. Still another factor suggested by the Prince Albert Studies[3] is the possible attenuation of the signal due to chirp effects. There are probably more ambiguous parameters still undefined. A considerable amount of research must be done if all of the Z parameters are to be successfully factored out and mathematically represented. For the time being, it will be necessary to exercise great caution when comparing Z's measured by different radars. This section will be devoted to exploring ways to use Z for comparative measurements.

3.1 Comparative Measurement Techniques

Certain types of useful multiple radar measurements can be made which do not require comparison of absolute quantitative reflectivity. These include definition of the location, extent, and morphology of the auroral event. The prime factor of importance is that these radars be capable of obtaining measurable backscatter from the region of mutual interest. If the aurora is of the diffuse type, the characteristics of the aurora may not change considerably over a rather large region, allowing each radar to observe different, but nearby regions which will produce similar measurable returns. The prime criterion is that from the common region of observation each participating radar be capable of collecting a significant quantity of backscatter data with a suitable signal-to-noise ratio.

Assuming that useful data has been obtained, aspect sensitivity can be mutually investigated. Aspect dependence is relative, meaning that

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[3] Jaye, W. E., Chestnut, W. C., and Craig, B., Analysis of Auroral Data From the Prince Albert Radar Laboratory, Stanford Research Institute, Menlo Park, California, September, 1969.

reflectivity can be normalized. Furthermore, it is apparent that aspect sensitivity is not dependent on the frequency of the radar[4] and, therefore, normalized aspect response data can be compared directly.

There are, of course, many types of studies where direct comparison of reflectivity would be desirable. It has already been noted that when different radars observe the same region containing scatters, the measured Z will vary depending upon the location and operating frequency of the individual radars. If UHF and higher frequency radars operate within 100 MHz of one another, differences due to frequency will generally not exceed 3dB[4] In such instances, comparative Z measurements can be made by considering only data measured on a mutually convenient off-perpendicular surface contour. By using this scheme, the effects of aspect sensitivity are minimized. This also means the radars will not be observing exactly the same region of space. Preliminary investigation will be required to determine if the regions observed by each radar are similar enough to justify comparison. This type of study may be limited to quiet forms of aurora which do not exhibit large scale, highly fluctuating behavior.

Another important precaution is to avoid comparisons of data from single pulses. The backscattered power received by the radar results from the combined amplitude and phase contributions of all scatterers within each range resolution cell. The motion of these scatterers is dynamic and, thus, their individual phases are rapidly changing. This results in backscattered pulses which are completely decorrelated in less than 20 msec.[5,6] This certainly ensures that for most radars the pulse-to-pulse received signals will be uncorrelated.

The pulse-to-pulse auroral signals have been found to obey a well-behaved amplitude distribution[7], as shown in Figure 3-1. It will be necessary to average corresponding range cells from approximately six pulses to reduce the standard deviation in the calculated Z to 3dB or less. Thus, through careful planning of measurement technique and analysis of selected regions, it should be possible to obtain multi-radar auroral measurements which compare within a few dB.

3.2 Removing the Ambiguities from Z

It was promised in the first section that a method would be discussed which suggested the possibility of deriving a Z nearly free of ambiguous

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[4] Egeland, A., Holter, O., Omholt, A., Cosmical Geophysics, Scandanavian University Books, Oslo, 1973, p. 315.

[5] Ibid, p. 64, 317

[6] Ibid, p. 316, 317

[7] Ibid, p. 64, 317

TWO CURVES OF RADAR AURORAL SCATTERED POWER VS. FREQUENCY[7]

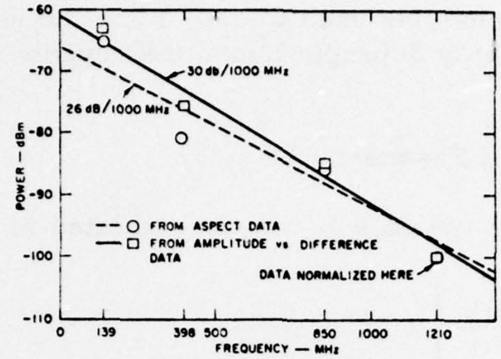

Figure 3-1

OBSERVED AMPLITUDE DISTRIBUTION COMPARED WITH A THEORETICAL CALCULATED RAYLEIGH DISTRIBUTION[8]

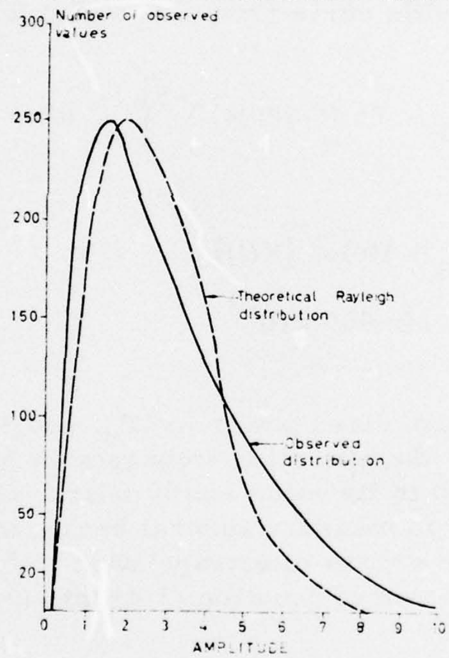

Figure 3-2

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[8]Chesnut, W. G., Hodges, J. C., and Leadabrand, R. L., 1968; Report No. RADC-TR-68-286. Stanford Research Institute.

[9]Egeland, A., 1962a: Arkiv for Geofysik 4, 103.

unfactorable radar parameters. It was also pointed out that this method is highly empirical in nature, relying on the results of the many past auroral experiments. Nevertheless, from the information available an improved Z' term will be derived. The accuracy and usefulness of Z' will be no better than the hardware and analysis used to determine the necessary parameters. The results are also highly dependent upon the repeatability of those measurements.

3.2.1 Normalization of Frequency Effects

It is desirable to obtain a Z' which is related to Z, expressed by equation (2.11), by

$$Z' = \left[\frac{K(f)}{G_S(\alpha)}\right] Z \qquad m^2/m^3 \tag{3.1}$$

where K(f) is a frequency dependent proportionality factor. Chestnut[10], through experimentation, generated a relationship between auroral scattered power and frequency. Experimental curves are shown in Figure 3-2.

The 26dB/1000 MHz curve from the aspect data can be represented by

$$P_N = \left[P_M + 26\,(f-400)\times 10^{-3}\right] \qquad \text{dBm} \tag{3.2}$$

or

$$P_N = P_M + 10 \log \left[K(f)\right] \qquad \text{dBm} \tag{3.3}$$

where

$$K_f = 10^{2.6(f-400)\times 10^{-3}} \tag{3.4}$$

and where P_N is the normalized power in dB_m and P_M is the measured power in dBm, and f is the operating frequency in MHz. Furthermore, the power is normalized to its value at 400 MHz. This is representative of the frequencies used to measure auroral backscatter and will, therefore, help to reduce the errors of extrapolation. Upon substituting the frequency normalizing term of equation (3.4) into (3.1), one obtains

$$Z' = \frac{Z\,10^{2.6(f-400)\times 10^{-3}}}{G_s(\alpha)} \qquad m^2/m^3 \tag{3.5}$$

[10] Egeland, p. 42

3.2.2 Normalization of Aspect Dependence

If it were possible to generate an accurate mathematical description for $G_s(\alpha)$, the Z' data could be corrected for aspect effects. This operation could be performed on a point-by-point basis. Within the available literature a number of empirical equations for $G_s(\alpha)$ have been developed. The various relationships compare loosely in their representation of $G_s(\alpha)$. Attempts have been made to generate composite relationships by fitting curves through data from various sources. Analysis is restricted because of radar power and sensitivity as well as radar location, thus allowing only a limited band of off-perpendicular angles to be included in analysis. Furthermore, some of the aspect sensitivity studies were performed using only received backscattered power measurements which had not been normalized to account for radar parameters such as illuminated volume. Care must be exercised in comparing the results of some of these studies because of the inherent dependence of the results on radar parameters and echo range.

4. THE M&S COMPUTING AURORAL STUDY[11]

An effort is presently underway which may result in an improved representation of the aspect relation. This study is being performed by M&S Computing, Inc., in Huntsville, Alabama, for the Army Ballistic Missile Defense Command (BMDSCOM). Data to support this study was collected using the Army Perimeter Acquisition Radar (PAR) located near Cavalier, North Dakota, at a latitude of 48.72° and longitude of -97.9°. This radar has many features which make it attractive for use in the study of auroral backscatter. Among these are its exceptionally high output power, sensitivity, and excellent resolution. The PAR also has the capability to rapidly scan very large areas because of its completely electronically steerable phased array and high performance data processing system.

An intensive study is being performed using the auroral data collected from the PAR. This includes not only an analysis of auroral backscatter, but also simultaneous associated effects on tracking performance using a number of specially selected satellites.

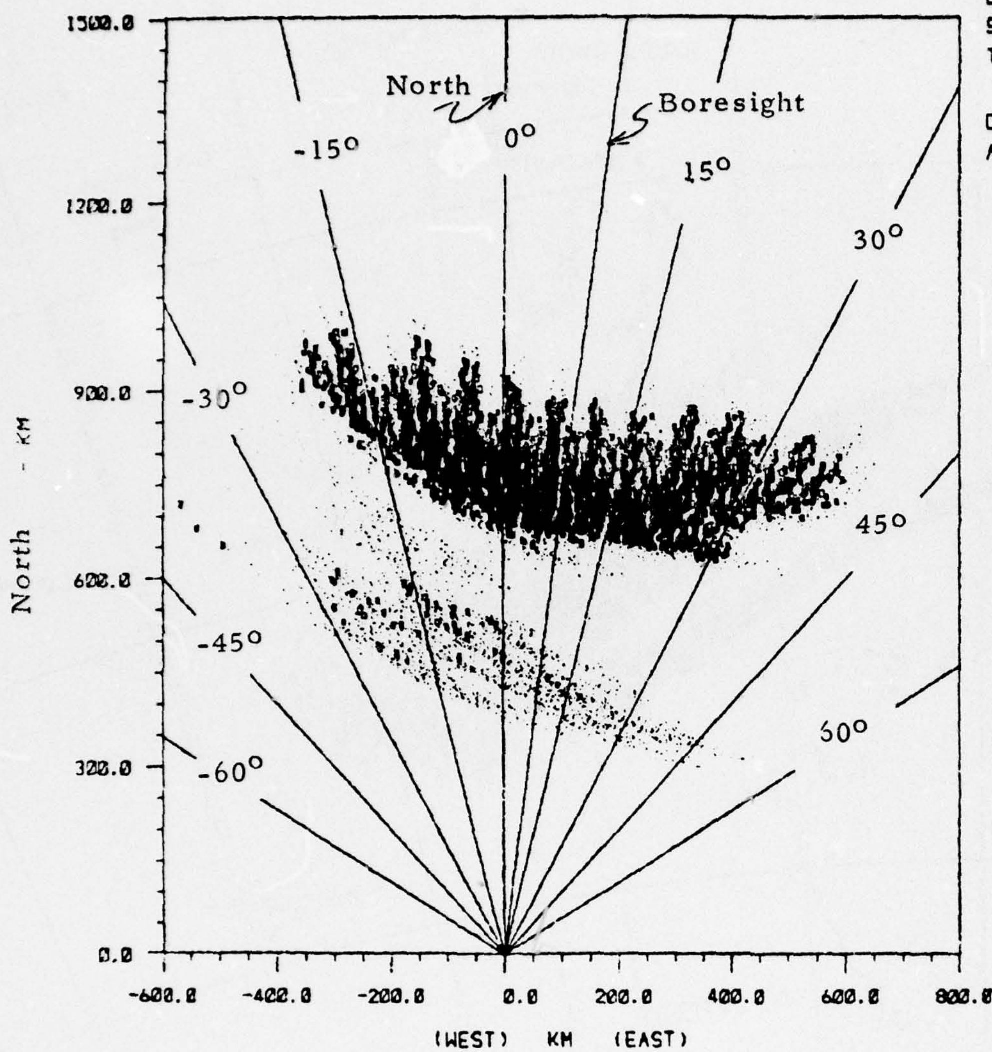
4.1 Auroral Data Analysis Tools

A number of auroral data reduction tools have been developed by M&S Computing to support the auroral analysis. These include programs for the generation of auroral backscatter maps of various projections such as the "Top Down" and "Profile" types. Figure 4-1 shows an example of an auroral reflectivity map with a planar tangent projection. The locations of the auroral echoes are projected on the surface of the earth. The size of each character corresponds to the level of the auroral reflectivity measured in decibels with respect to 1 m^2/m^3 or dBm^{-1}. At this time no attempt has been made to apply the corrections for frequency and off-perpendicular angle. Auroral reflectivity maps actually consist of 10 overlays, each corresponding to altitude slices of approximately 10km thickness. Figure 4-2 is an auroral reflectivity map plotted on a map of North America; the location of the PAR is designated by the symbol Δ located near Grand Forks, North Dakota. This map shows a composite of all altitudes from 70 to 170km.

The "Profile" plots map the auroral backscatter onto a plane parallel to the bisector of selected azimuth slices. Points within the slices are rotated into the plane such that the correct radar range is maintained. Presently 10 azimuth slices are generated. They may be observed singly or in multiple overlays of any combination. Figure 4-3 is a profile of the same aurora as in the previous figures. It is a composite of all azimuth angles from -30° to +45°. Also shown on the Profile plots are curves of constant elevation angle and constant off-perpendicular angle. These

[11] PAR Auroral Study, Volume I, M&S Computing Report No. 76-0013, March 15, 1976.

TOP-DOWN VIEW OF AURORAL PHENOMENA AT PAR



BEAM: BOTH
SCAN: 317
TIME: FROM 270/ 3/ 4/40
TO 270/ 3/ 5/ 0
DATA THINNING FACTOR: 2
ALT (KM): 70.0 TO 170.0

ALTITUDES	ON LEVEL
70.0 TO 80.0 KM	5
80.0 TO 90.0 KM	6
90.0 TO 100.0 KM	7
100.0 TO 110.0 KM	8
110.0 TO 120.0 KM	9
120.0 TO 130.0 KM	10
130.0 TO 140.0 KM	11
140.0 TO 150.0 KM	12
150.0 TO 160.0 KM	13
160.0 TO 170.0 KM	14

Figure 4-1

AURORAL MAP REPRESENTATION

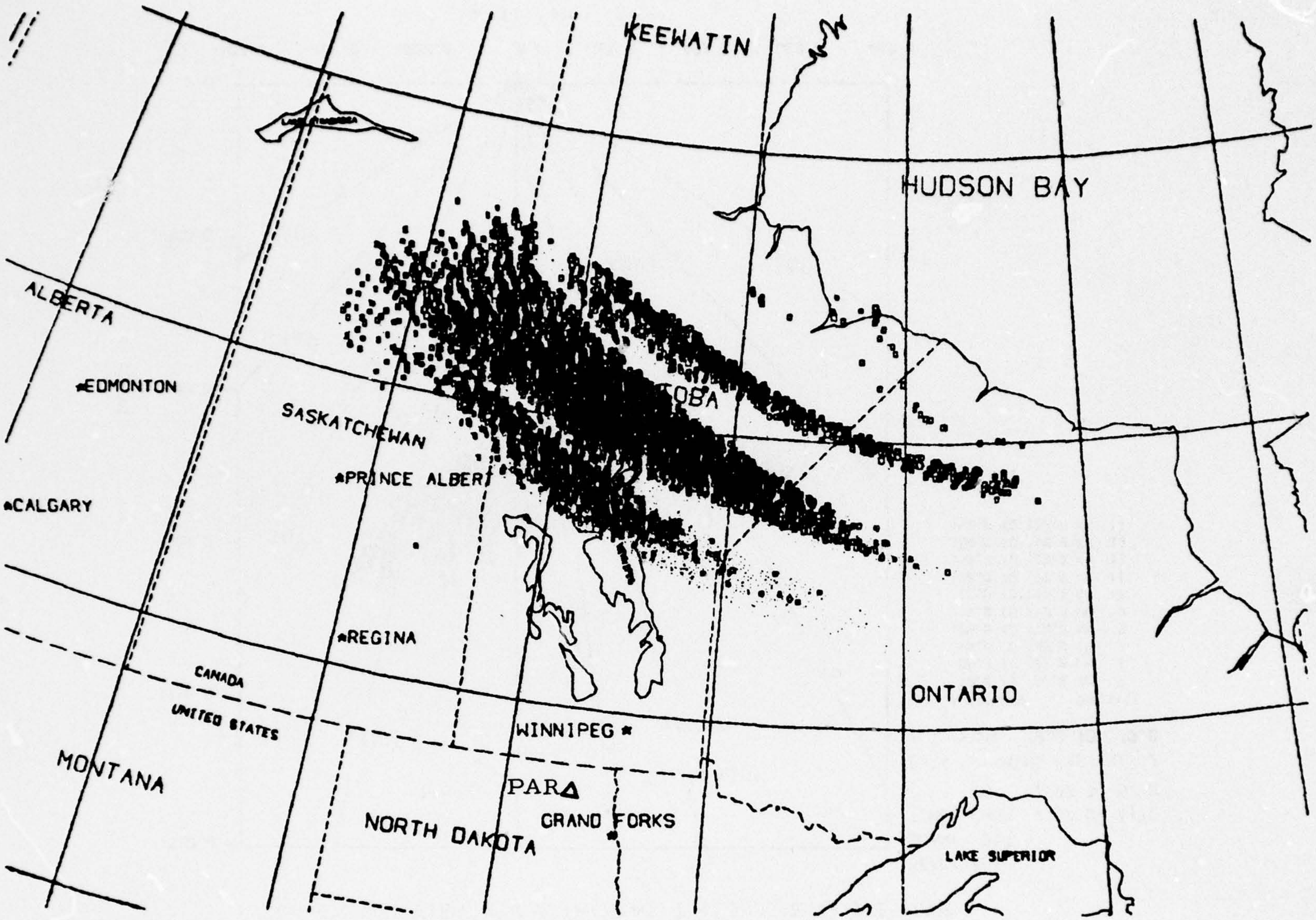


Figure 4-2

COMPOSITE AURORAL PROFILE

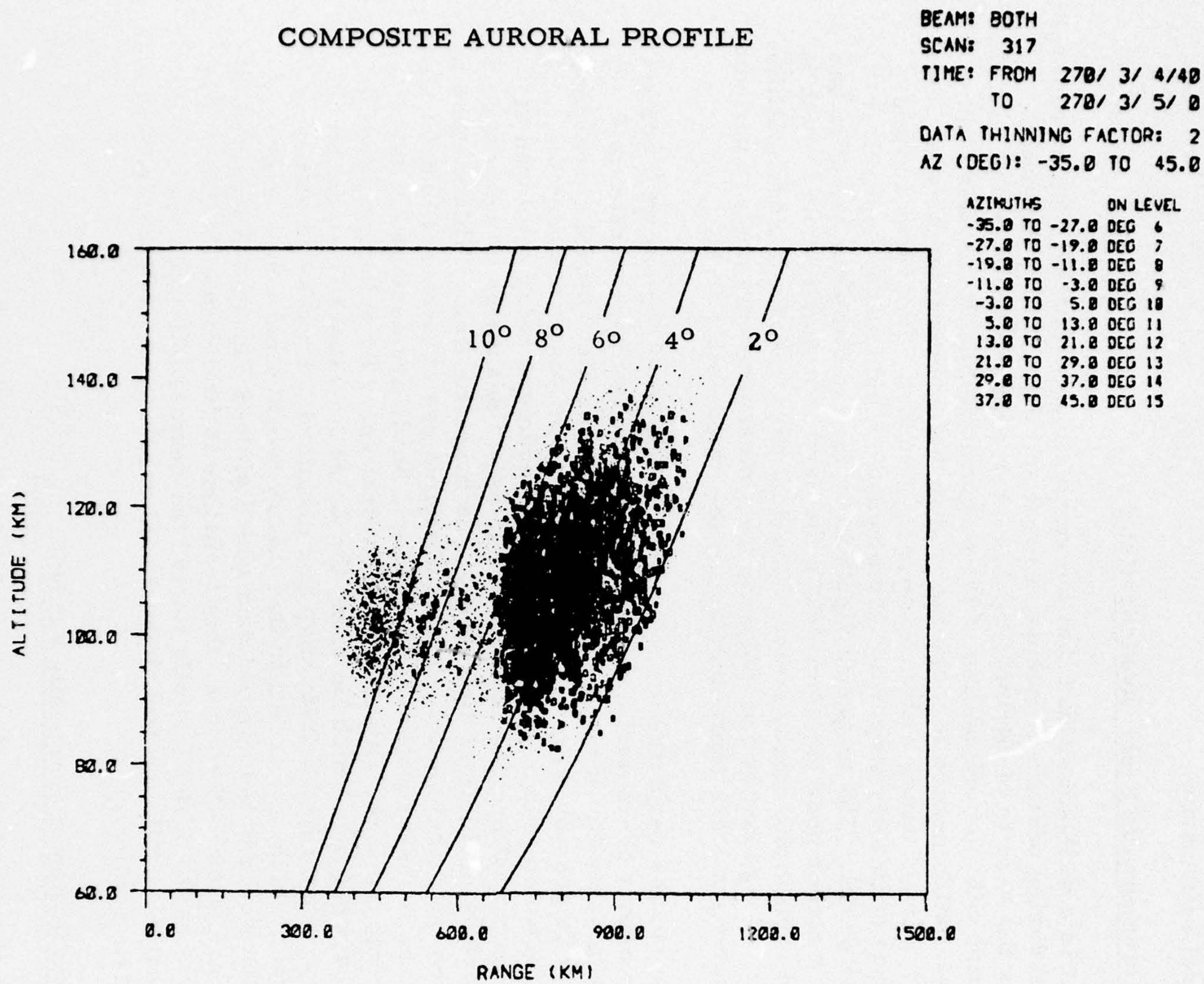


Figure 4-3

auroral maps are useful in more detailed studies of auroral phenomena and especially in studies of the relationship of magnetic field aspect angle to auroral reflectivity.

4.2 Geomagnetic Field Considerations

It is a well-known fact that the earth's magnetic field may be severely distorted during periods of intense auroral activity. This phenomena degrades the results of attempts to characterize the relationship of auroral backscatter with the orientation of the magnetic field and the radar beam. This degradation occurs because the researcher must perform aspect calculations using a steady state magnetic field model. Two types of field models are commonly employed, the magnetic dipole and the spherical harmonic model. The magnetic dipole is by far the simplest model to use but does a rather poor job of modeling the earth's magnetic field, which is distorted even in the steady state. Spherical harmonic field models utilize data from a large number of magnetic field measurements and can produce a reasonably accurate representation of the steady state field.

In studies requiring the selection of data from regions with certain magnetic aspect characteristics, it is important that an accurate field model be employed. It is also important that this field model correspond as closely as possible to the magnetic field conditions at the time the auroral backscatter data was collected. A technique being employed at M&S Computing allows the investigator to select quantities of auroral data during periods of minimal distortion in the magnetic field. This method is based upon the principle that auroral particles are constrained to drift along the constant L shell contours. The auroral bands are assumed to lay along L shell contours at the altitude of the auroral arc. By selecting auroral data displaying bands which lie along the L shell contours from the field model, the errors in the study may be minimized. Figure 4-4 shows an auroral map which, according to this theory, would yield a good aspect correlation whereas the auroral data which yielded Figure 4-5 would yield a poor correlation. Of course, this technique is limited especially in that large scale shifts of the L shells toward the geomagnetic pole are not recognizeable. Still, the technique should result in a considerable improvement in data quality.

4.3 *Generation of Composite Scans*

Another technique being used involves the generation of composite scans or "Superscans". These Superscans consist of the point-by-point averaging of all the auroral echoes from a number of independent scans. As discussed in Section ?.1., auroral echoes are completely decorrelated

TOP-DOWN VIEW SHOWING GOOD L-SHELL ALIGNMENT

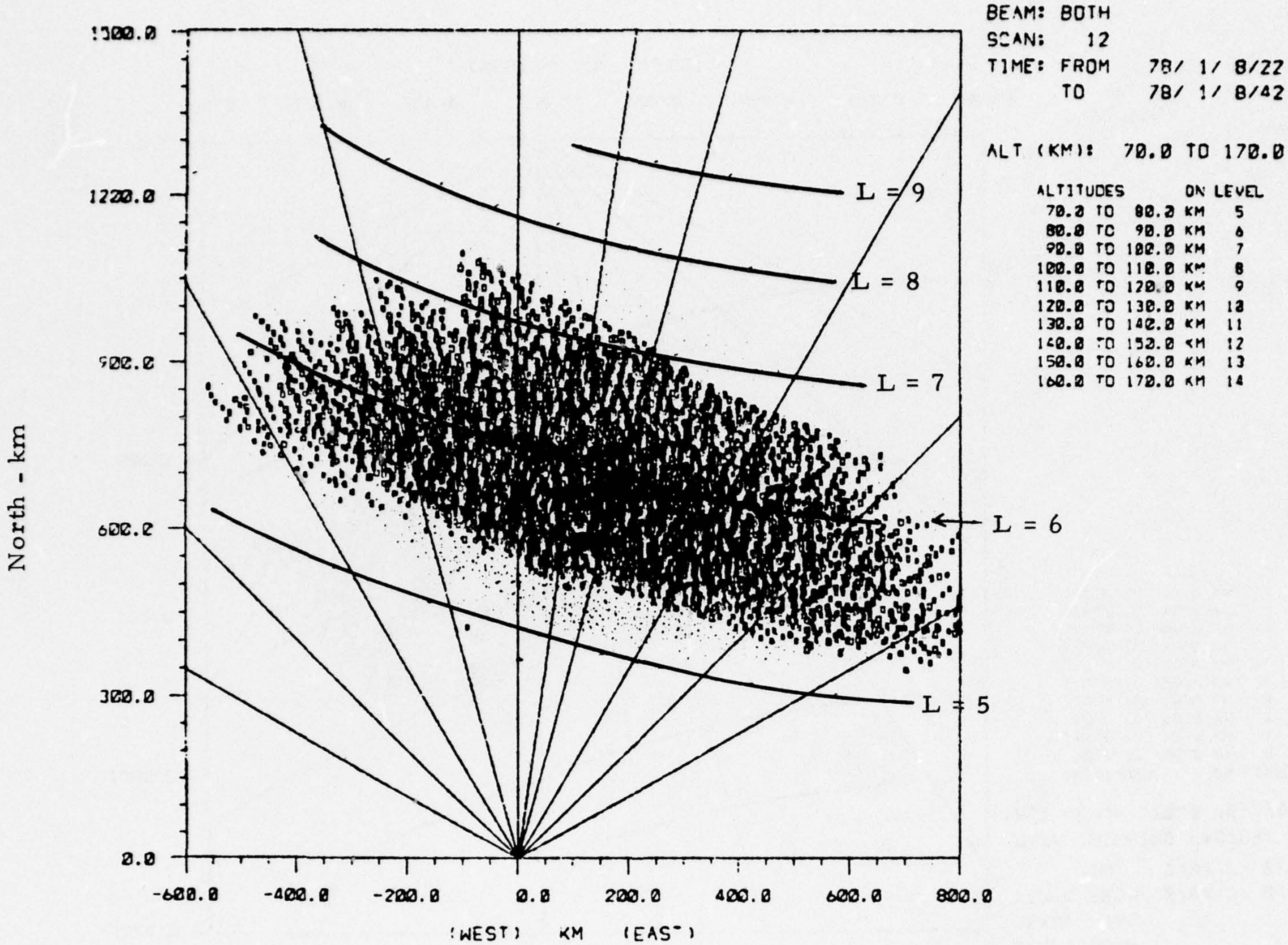


Figure 4-4

TOP-DOWN VIEW SUGGESTING POOR L-SHELL ALIGNMENT

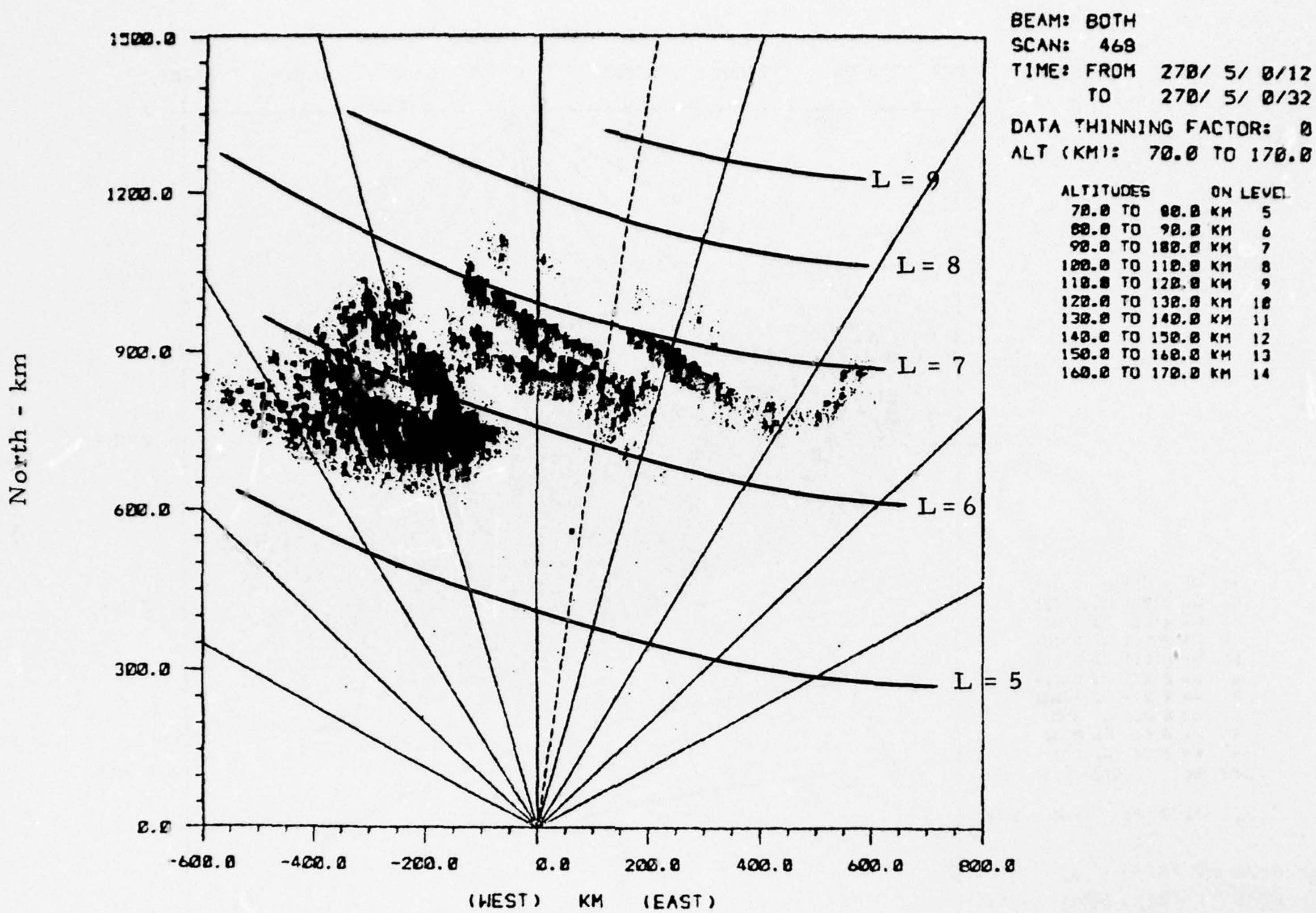


Figure 4-5

if the interpulse spacing is greater than about 20ms[12], and that the echoes from subsequent pulses obey a statistical probability of occurence distribution such as shown in Figure 3-1. The point-by-point averaging of the echoes from several scans will reduce the standard deviation of this distribution and the averaged values will approach their expected value. Superscan data from narrow altitude bands will be processed by a scatter plot program which will produce a plot of reflectivity versus off-perpendicular angle. A Chebyshev curve fitting routine will be used to produce a best fit to the scatterplot. If the results are consistent over a large number of test cases, the resulting polynomial will be used as a model for the aspect term $G_s(\alpha)$.

4.4 The Problem of Nonzero Beamwidth

Still another technique for improving the data quality is being investigated. This involves the problem of beam overlap and multiple detects. When observing large scale volume scattering regions such as aurora, the detected echoes are actually the superposition of signals received from all angles. It cannot be assumed that the reflecting cell can be confined within the commonly defined 3dB radar beamwidth. In reality, a portion of the received energy may originate from regions where the two way radar beamwidth is 65dB or more down from its boresight value. The effect is to increase the apparent signal strength of all echoes from large regions filled with auroral scatters. The radar continues to detect backscattered power from the natural auroral boundaries even after the beam axis no longer penetrates the aurora. This effect tends to expand certain apparent boundaries and reduce their sharpness. The overall effect of this nonzero beamwidth is a loss in resolution and a distortion of all measured signal strengths.

The present investigation relies heavily upon the theories of radar antenna pattern analysis in an attempt to develop a processing scheme which can be used to correct the auroral echoes for the described effect. For the present, these effects are being minimized by the careful choice of data to be used for aspect studies. This choice is based upon the author's belief that within a large, fairly uniform backscattering region the effects of nonzero beamwidth will produce a uniform and consistent distortion to all the auroral echoes. Further, the relative aspect dependent characteristics of the echoes from this reflecting volume will still be representative of those which might be determined in the ideal case. When normalized, the reflectivity versus off-perpendicular angle relationship can still provide a valuable measure of the aspect dependence of auroral backscatter.

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[12] Egeland, p. 64, 317.

5. CONCLUSIONS

A need has been identified for the development of a standardized method for the representation of auroral backscatter data. A technique has been proposed here which may be employed to calculate a general auroral reflectivity parameter. An equation, which describes auroral reflectivity with normalized magnetic aspect dependence, has been presented. Published data describing the magnetic aspect relationships will be combined with the results of present research at M&S Computing, Inc., to develop an empirical relationship which can be combined with the reflectivity equation described herein and thus attempt to resolve the ambiguous aspect parameter, defined as $G_s(\alpha)$.

In order to enhance the dependability of the results of the analysis performed, the auroral backscattered data must be carefully screened. The author has described various ways to improve this selection process by the use of auroral maps and L shell contours. The problems associated with multiple detects and the nonzero beamwidth have been presented, and ways to minimize this problem were discussed.